

## High Resolution Electron Microscopy of Grain Boundary Motion During Island Grain Shrinkage

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The shrinkage of small island grains has attracted increasing recent interest because of its direct relationship to the mechanism of interface migration and the question of shear-migration coupling. Detailed TEM studies of island grains in Al [1] and Au [2] found that interface motion was erratic and proceeded at a rate that was inconsistent with parabolic kinetics. Instead it was characterized by bursts of rapid, localized motion alternating with long periods of stagnation in an irregular sequence, and migration was controlled by step motion. Here we investigate the role of these steps in more detail.

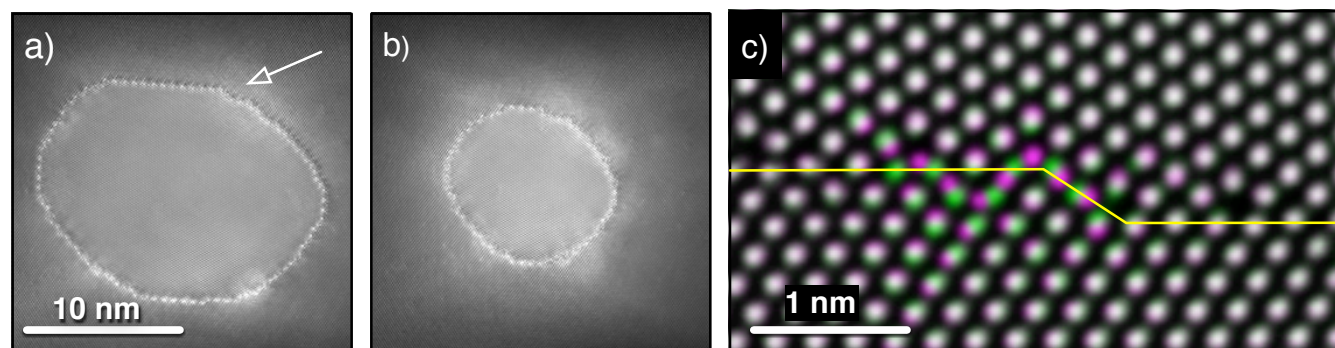
Using atomic resolution electron microscopy, we have observed the shape, interface structure and shrinkage of island grains under capillary forces in  $90^\circ$   $\langle 110 \rangle$  bicrystals of Au at  $300^\circ\text{C}$ . Statistical measurements of the grain shape evolving during shrinkage indicate a strong preference for three characteristic facets, denoted A, B and C [2]. The C-facet is most prominent and controls the rate of shrinkage. This facet consists of (100) planes of one grain lying opposite (011) planes of the other grain. Such boundaries are incommensurate because the repeat periods of lattice planes of the two grains that are aligned across the interface are in the ratio of  $1:\sqrt{2}$  [3]. Migration of these facets is limited by interfacial steps. This is illustrated in Figure 1, which shows 2 out of a sequence of 56 HRTEM images recorded at  $210^\circ\text{C}$  (a,b). The arrow in (a) marks a C-facet containing a step. The atomic displacements during the lateral motion of a step in this interface under the influence of the electron beam are shown in (c), where HAADF images taken before and after step motion are added to form an RGB image that shows stationary atoms in white and moving atoms in color. Using molecular dynamics simulations based on experimental observations, a collective mechanism of motion was found, related to constriction/expansion of a short stacking fault attached to the step [4].

To further investigate the details of interface motion during capillary shrinkage, a dynamic tracing of the island grain over a period of about 30 minutes at  $300^\circ\text{C}$  is shown in Figure 2. The preference for C-facets (horizontal and vertical segments) and the erratic nature of interface motion (uneven spacing between sequential outlines) are readily apparent. A more detailed view of the upper C-facet (dashed outline in (a)) is shown in a magnified view in (b), which represents an overlay of 8 sequential frames. By examining these 8 frames separately (1-8), it becomes apparent that the C-facet remains stationary while it is shortened by inclined facets encroaching from the sides. The shortened C-facet moves only in the last frame, where it is seen to have advanced by a large increment. This tendency for discrete jumps is highlighted in (c), which shows a magnified view of the region marked by a shaded rectangle in (a). The characteristic increments are indicated by heavy gray lines. The preference for these jumps and the statistical frequency observed for different steps will be discussed in terms of a model for grain boundary motion in this and similar materials.

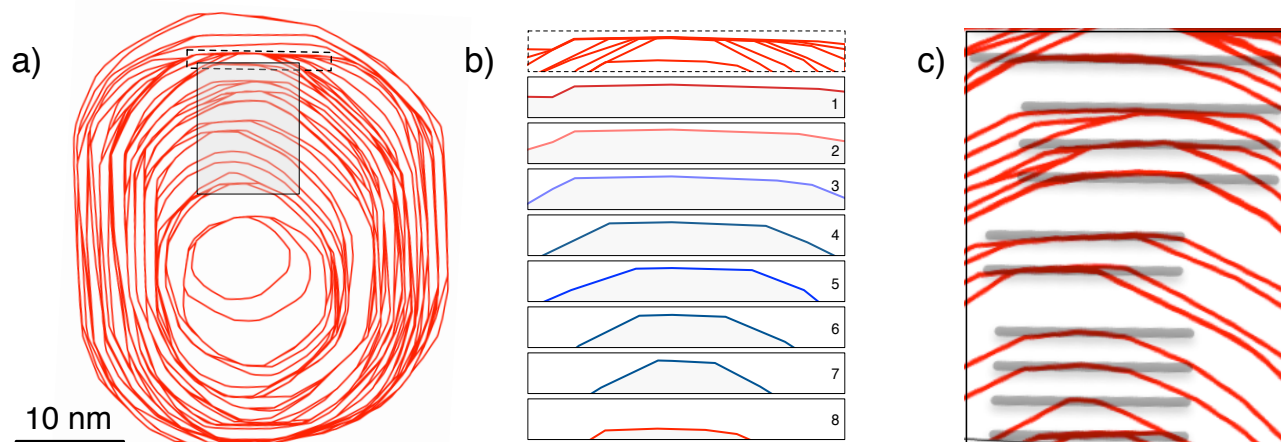
This talk is dedicated to the memory of Gareth Thomas, whose passion for electron microscopy and its application to characterize the microstructure of materials inspired a generation of microscopists [5].

## References

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- [5] Work at the NCEM/Molecular Foundry was supported by the Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.



**Figure 1.** a,b) frames from a time sequence of HRTEM micrographs recording the shrinkage and disappearance of an island grain during in-situ observation at 210°C; c) HAADF image highlighting atomic displacements during beam-induced step motion; interfacial step outlined by yellow line.



**Figure 2.** Dynamic tracing of the shape and position of the grain boundary surrounding an island grain during shrinkage at 300°C. Outlines were obtained from a sequence of 56 high resolution images, recorded at 2k x 2k, in intervals of about 35s. The concentric sequence in a) demonstrates the anisotropy of the interface and the irregularity of its motion. The dashed horizontal rectangle highlights the shrinkage of a stationary C-facet by encroachment from neighboring inclined interfaces. This process is shown in more detail in b) where 8 sequential positions of the shrinking grain are overlaid in the top frame and shown separately in the following 8 frames (1-8). In c) a rectangular section of the shrinkage sequence (shaded in a) is marked with gray bars at characteristic intervals to emphasize the tendency of the interface to move in discrete increments.